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"Recombination in the Nighttime F Region from Incoherent Scatter Measurements"

by

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UNPUBLISHED PRELIMINARY DATA

ABSTRACT

Previous measurements of recombination coefficients in the F-region by Quinn and Nisbet (1965) were made using ion density profiles derived from reduced ionograms. Uncertainties resulted due to the lack of information on the profile of the top of the layer, on the temperatures of electrons, ions and neutral particles and about the profiles in the lower F-region at night.

Profiles obtained at the Arecibo Ionospheric Observatory have been used to study the nighttime recombination. It is shown that at Arecibo large changes in the electron ion temperature ratio do occur at night in winter under low sunspot conditions up to about 0200 hours. Such changes were one mechanism previously postulated to explain low values of recombination coefficient obtained using the ionogram data for winter low sunspot conditions.

A considerable improvement in the consistency of the results is obtained by the use of the incoherent scatter measurements and it is now possible to derive recombination coefficients with reasonable agreement from hour to hour from twenty minutes of data.

Electron ion temperature ratios of greater than unity were observed throughout the night raising the question of nighttime production and the effect of this on the results is discussed. [redacted]

author

1. Introduction

In a previous paper Quinn and Nisbet (1965) have examined the recombination and diffusion processes at night using electron density profiles reduced from ionograms.

For these analyses it was found necessary to study the layer as a whole because of the importance of downward transport of ionization through the maximum. This required that certain assumptions be made about the shape of the top of the layer, or at least about the changes in the content above the peak as a function of time. The reduced ionograms did not of course extend beyond the maximum.

At night ionograms are subject to errors at lower heights due to dispersion in the lower regions of the ionosphere. It is in this region that the dissociative recombination coefficient becomes important and it is here that the lower boundary conditions for the transport velocity are established. It was thus necessary to correct the profiles to the extent possible and this was done using a series of correction factors developed by Long (1962). These measurements were compared with neutral atmospheric temperatures estimated using the mean monthly 10.7 cm solar flux and a relation derived by Jacchia (1952) from satellite retardation studies.

Incoherent scatter measurements of the ionosphere provide measurements of the electron density above and below the maximum. Measurements of the electron and ion temperatures, indicate the ionic mass and are not subject to dispersive errors in the lower ionosphere at night. A series of measurements has been made in cooperation with Cornell University at the Arecibo Ionosphere Observatory to investigate the effects of several of these factors. Recombination and diffusion coefficient calculations have been made and the initial results will be described. Previous work had shown large differences between the summer and winter behavior of the nighttime ionosphere and this difference was substantiated by the summer and winter measurements at Arecibo.

2. The Shape of the F region above the maximum

The shape of the electron density profile above the maximum in the region where diffusion effects dominate and atomic oxygen is the major ion is dependent on the sum of the electron and ion temperatures. Figure 1 shows electron and ion temperatures for one summer and one winter night. In winter the electron temperatures in the upper ionosphere decrease steadily throughout the night until 2:30 at which time they start to increase again. This effect is discussed by Carlson and Nisbet (1965) and is attributed to photo-electrons from the conjugate area traversing the field lines and producing heating of the electrons in the upper ionosphere. In summer the electron temperature drops rapidly in the first two hours after sunset and then remains stable at a value higher than the ion temperature, throughout the remainder of the night.

Figure 2 shows comparative values of the plasma scale height calculated for a summer and a winter night. Values are given calculated from electron and ion temperatures measured using the incoherent backscatter spectra assuming O^+ as the major ion and from the relation given by Jacchia (1962) assuming that T_i and T_n are equal. It is apparent that on both the summer and winter nights the effect of the electron temperature being much larger than the ion temperature raises the plasma scale height considerably alone that corresponding assuming T_e, T_i and T_n equal. More important perhaps is the change in scale height as a function of time, for this controls the downward flux of electrons through the maximum. If such an effect is not taken into account for recombination coefficients calculated from profiles below the maximum the resulting recombination coefficients will be underestimated. The effect appears to be larger in winter when the conjugate location is illuminated for a good part of the night and thus the underestimation would be expected to be more serious in winter. An electron temperature that decreased throughout the night was one mechanism suggested by Quinn and Nisbet (1965) to explain the very low values of recombination coefficient calculated in winter under low sunspot conditions.

3. Effects related to the lower F region

In the previous analysis mean monthly ionograms were used which had been calculated by a modified Budden method. Such profiles have been shown to result in an underestimation of the electron densities at low heights and a correction based on the work of Long (1962) was applied.

In the present analysis incoherent scatter profiles have been used which do not suffer from these disadvantages. Figure 3 shows electron density profiles measured at night using the incoherent scatter profiles. On this graph also a profile is included reduced from an ionogram measured at the same time using a recent reduction method developed by Doupnik and Schmerling (1965). Such differences between the two types of measurements are currently being studied.

In the previous work diffusion coefficients were calculated. The decay in the electron densities at night was related to the recombination coefficient using neutral atmosphere models. These coefficients allowed the continuity equation to be integrated up to given heights to determine ion fluxes or ion velocities By comparing these ion velocities with normalized diffusion velocities calculated from the shape of the profile, diffusion coefficients were calculated.

This type of calculation is extremely sensitive to the assumptions made about the lower boundary condition and there was thus considerable uncertainty about the effect of the correction applied. It was therefore considered of considerable importance to repeat the analysis with more accurate data.

Figure 4 shows the vertical velocity in meters per second calculated for a twenty minute period at around 21:15 hrs. on July 12, 1964. Also shown on this graph is a normalized diffusion velocity. It is apparent that the characteristics of the velocity profiles are quite similar to those obtained previously. The diffusion coefficient calculated from these velocity profiles is,

$$D = \frac{2.16 \times 10^{19} \; T_n^{\frac{1}{2}} \; \sin^2 I}{n(M)} \quad m^2 \; sec^{-1}$$

From the limited number of examples calculated to date the indications are that the diffusion coefficients are larger than those estimated based on the ionograms as previously corrected. The results of the incoherent scatter measurements to date are only for two nights in summer under low sunspot conditions and much work remains to be done before conclusive statements can be made.

4. Recombination during a summer night

Figure 5 shows the total electron content as a function of time during one summer and one winter night. It is apparent that on the winter night in particular the electron content is not decreasing and in fact does increase during a major portion of the night.

During the summer night the electron content decrease was large during the period from 20 hours to midnight and the recombination coefficient calculated for individual periods was determined. These were found to be

α assumed	$\alpha = 3 \times 10^{-15}$ m^3 sec	$\alpha = 10 \times 10^{-15}$ m^3 sec^{-1}
21:07 to 21:22	$\beta_{300} = .985 \times 10^{-4}$ sec^{-1}	$\beta_{300} = .368 \times 10^{-1}$ sec^{-1}
23:15 to 23:55	$\beta_{300} = .789 \times 10^{-4}$ sec^{-1}	$\beta_{300} = .355 \times 10^{-4}$ sec^{-1}

No large trend is apparent in these measurements that would make it appear that the production rate is comparable with the loss rate during this period.

After this period howerer, the rate of change of electron content becomes very small and the difficulties apparent in the winter data are encountered.

5. Recombination during a winter night

In winter it is apparent that the integrated electron content did not in fact decrease during the night. This effect is apparent at all times even when the conjugate location is in darkness It is thus of interest to make an estimate of the nighttime production.

It was therefore decided to study the ionosphere throughout the day to determine production and loss coefficients for that day in another manner. Shortly after sunrise the production and rate of change of electron density terms predominate in the F_1 region continuity equation. It is therefore possible to determine the production profile at that time in the region of the production maximum even if the diffusion and recombination coefficients are not assumed to be known within an order of magnitude. Figure 6 shows profiles of the terms of the continuity equation at 6:45 calculated using data from the incoherent scatter sounder. The recombination coefficient values chosen for these calculations were taken from Quinn and Nisbet (1965).

The diffusion coefficient was chosen to be

$$D = \frac{4.5 \times 10^{19} \sqrt{T} \sin^2 I}{n(O)} \quad m^2 \sec^{-1} \quad ,$$

a purposly high estimate. It is apparent that the loss and diffusion terms are small in the region of 180 km and a value for the production function was adopted.

$$q = 2 \times 10^7 \quad \exp \left[1 - \frac{Z}{H} - \exp\left(- \frac{Z}{H}\right) \right]$$

The time period around 13 hours was next examined. It had been determined that at this time the region was stable at all heights and that it could therefore assumed that the production and loss terms would be approximately in balance. The production function determined after sunrise was modified to take account of changes in the solar zenith angle and in the atomic oxygen distribution. A production profile was calculated for this time and it is shown in Figure 6. The value of the recombination coefficient at 300 km was then calculated that would make the integrated production and loss in the layer equal.

This value was found to be

$$\beta_{300} = 0.71 \times 10^{-5} \sec^{-1}$$

and agrees well with mear nighttime values given by Quinn and Nisbet (1965) for the neutral temperature at that time.

Based on the recombination rate estimated at 13:00 hours the recombination rate was calculated as a function of height at midnight using neutral atmospheric models due to Nicolet (1962).

Figure 7A shows the thermal fluxes for midnight and 13:00 hours. Figure 7B shows the estimated production at 13:00 hours and the estimated loss at midnight calculated in the manner described. It is apparent that the total production required to maintain the nighttime ionosphere in winter is very much smaller than is present during the day. From these calculations it is estimated that on the night investigated a total production of the order of

$$Q = 10^{11} \text{ electrons } m^{-2} \text{ sec}^{-1}$$

would have been sufficient to maintain the observed electron densities. Production in this context should be interpreted as including any net ion flux downward at the 600 km altitude level.

Acknowledgments

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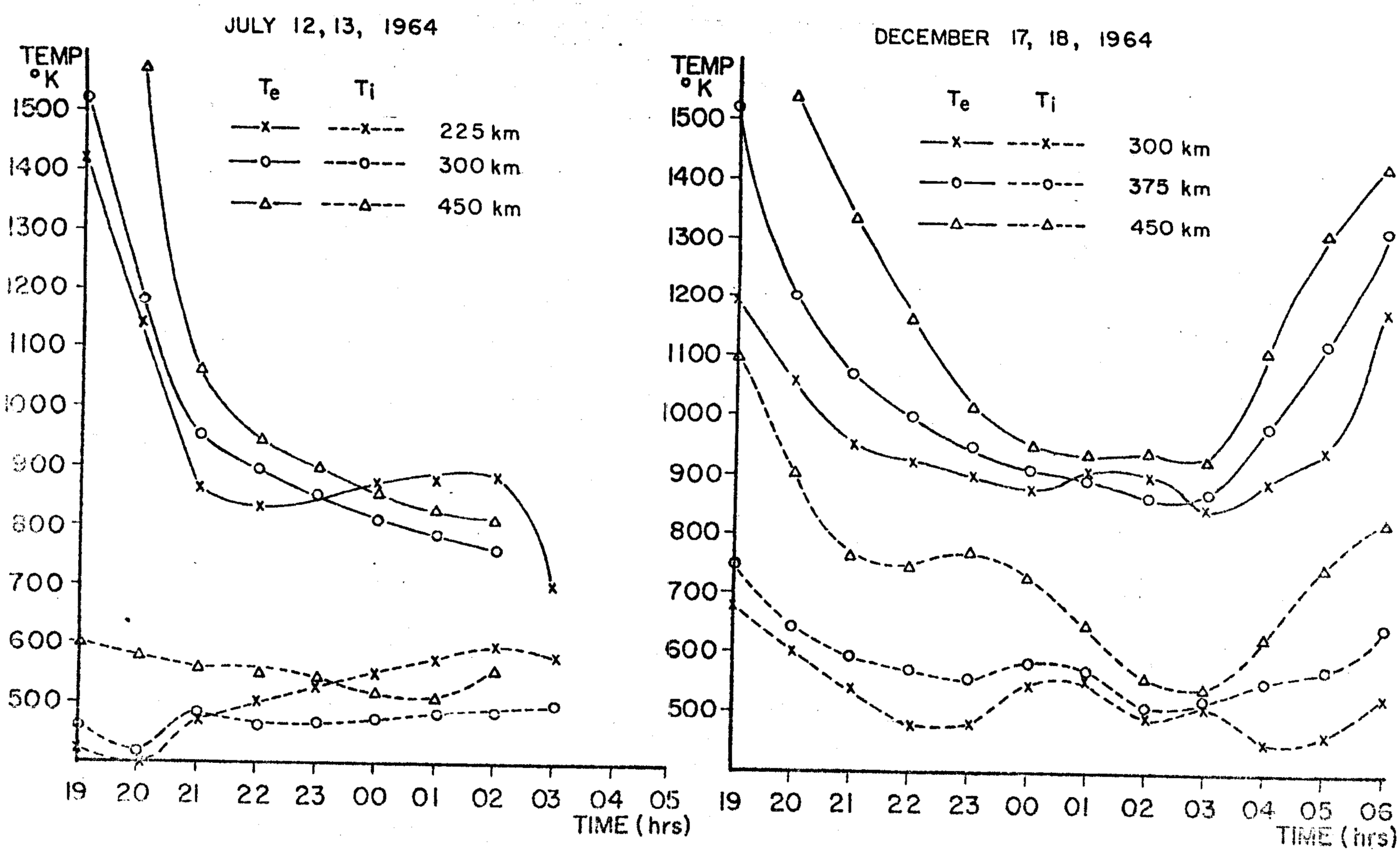
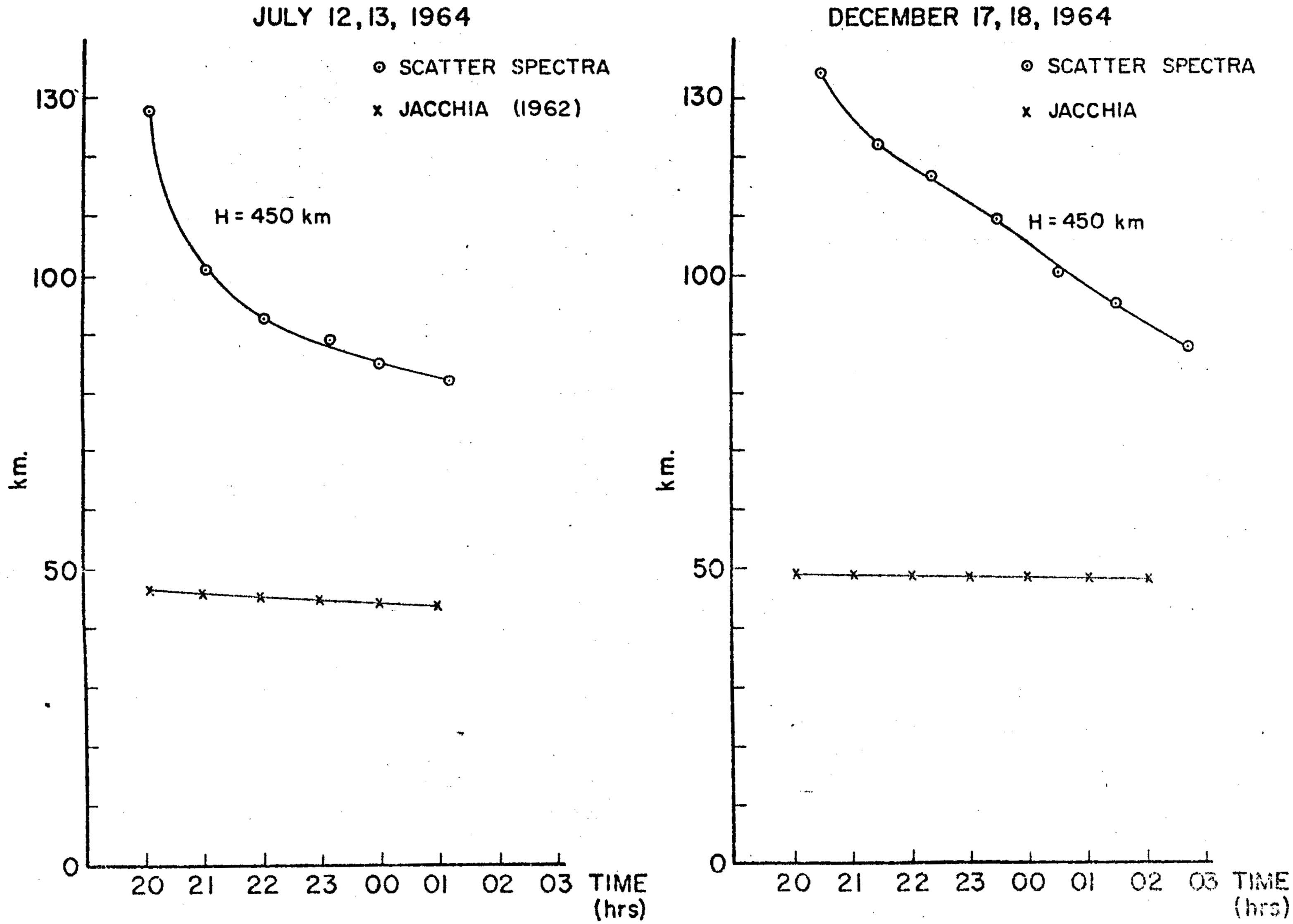


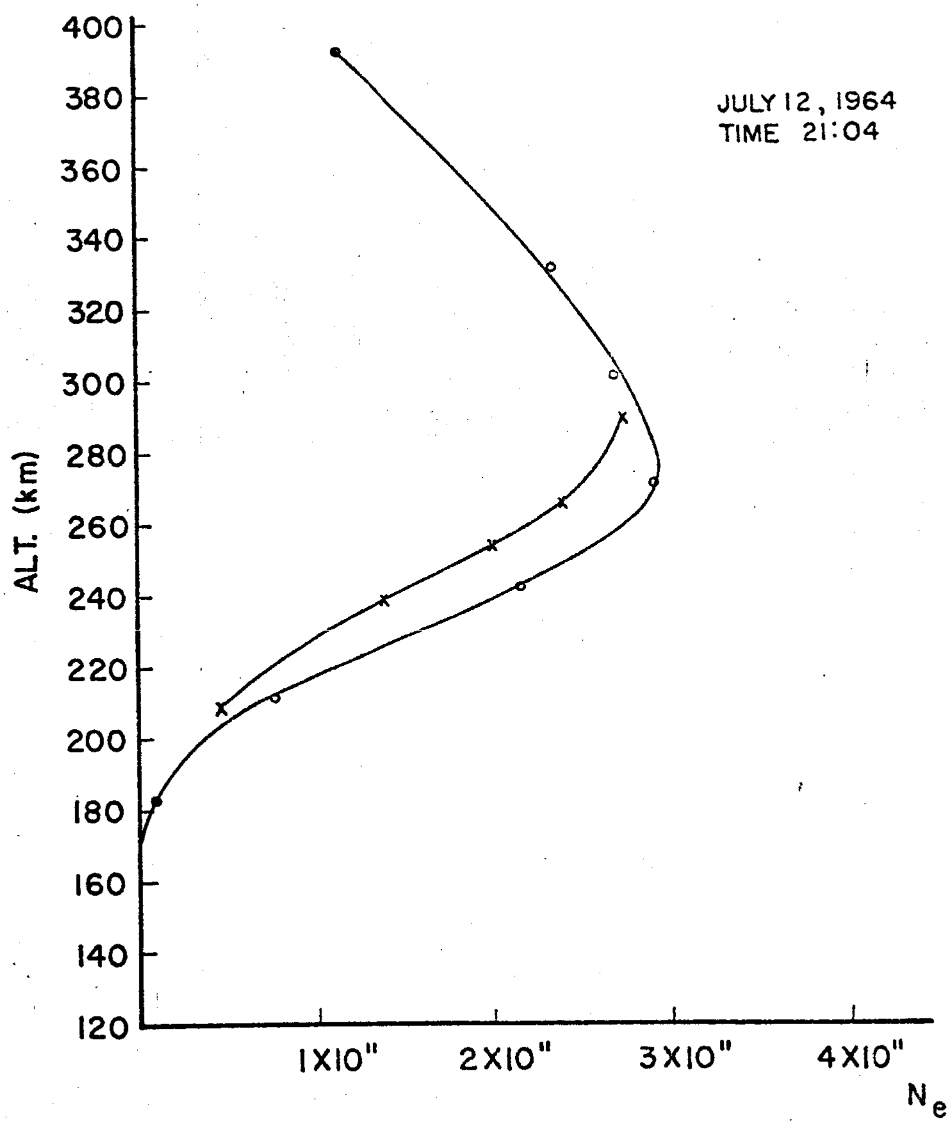
ION AND ELECTRON TEMPERATURES FROM BACKSCATTER

FIGURE 1



PLASMA SCALE HEIGHTS

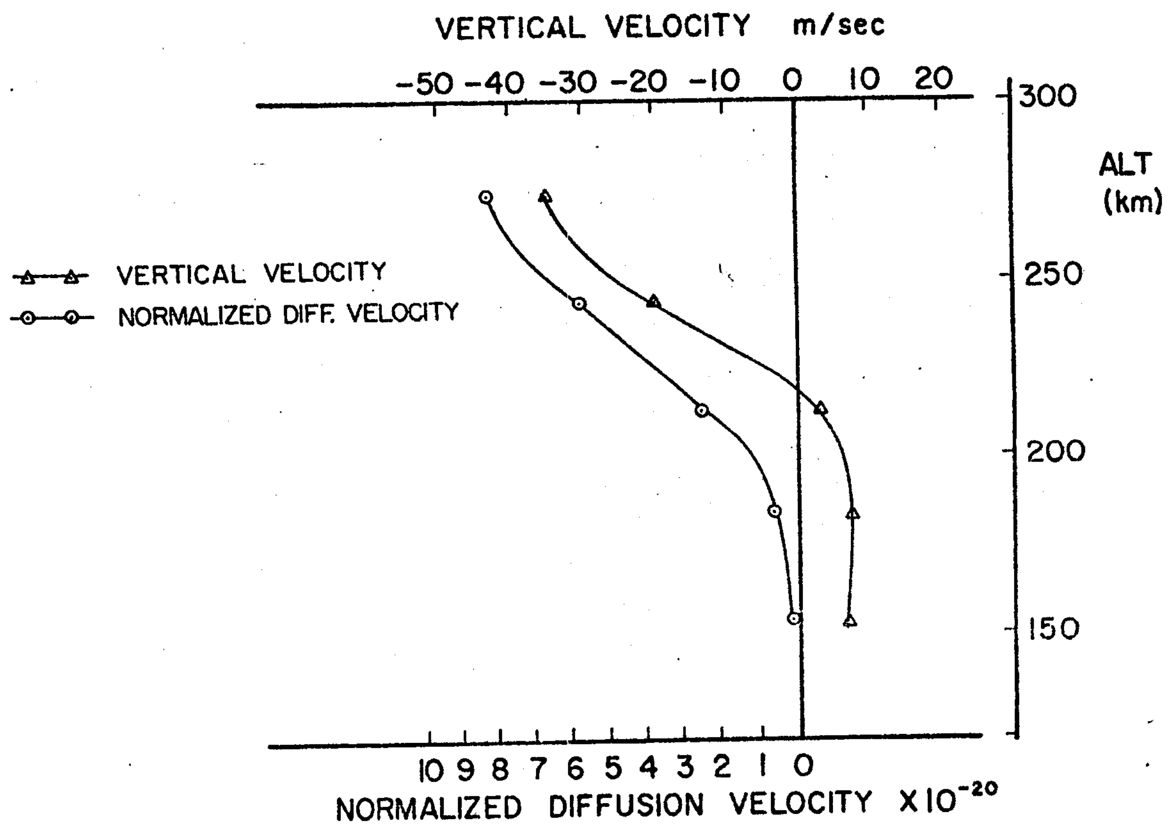
FIGURE 2



o ELECTRON DENSITY PROFILES FROM INCOHERENT BACKSCATTER

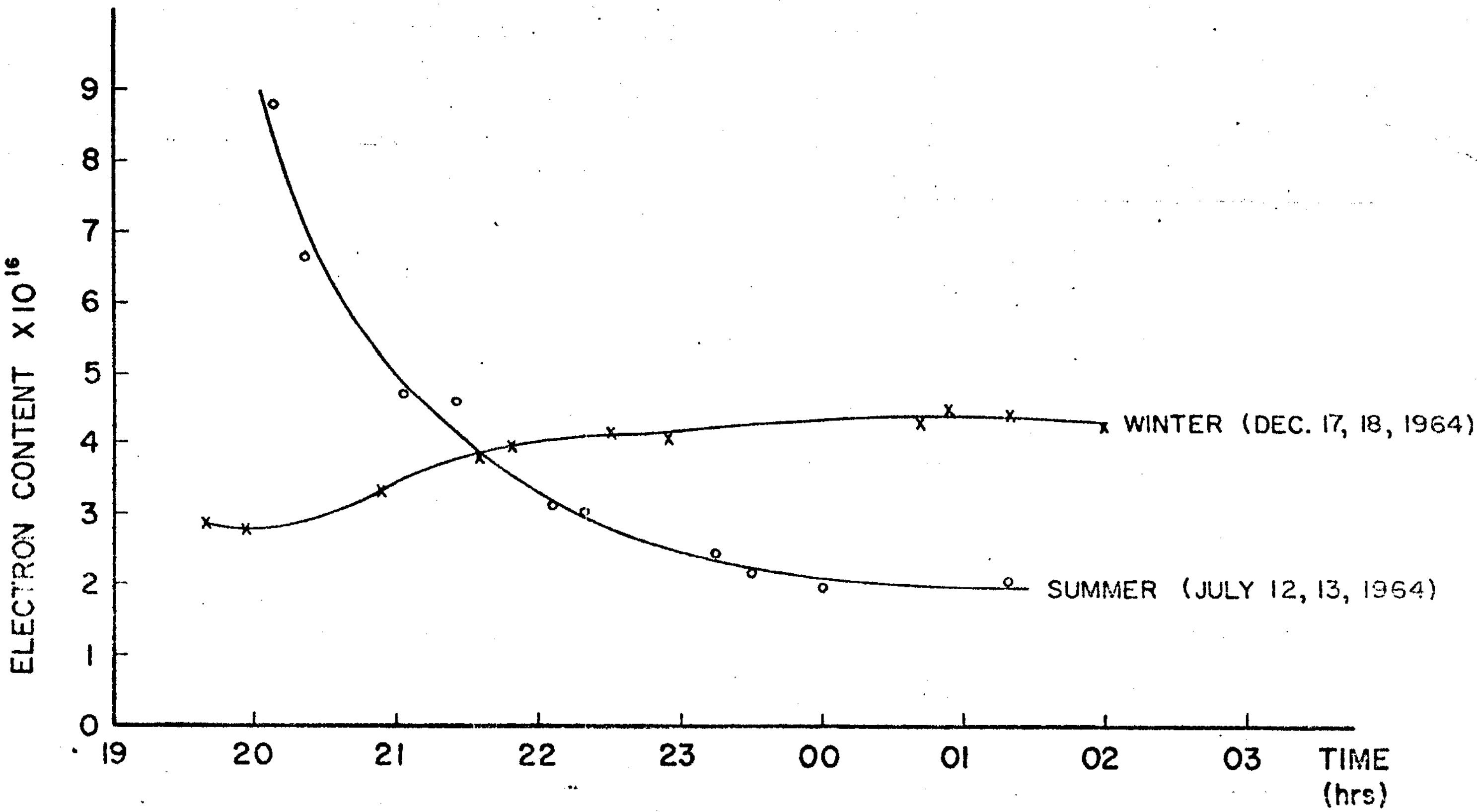
x TRUE HEIGHT PROFILE FROM IONOGRAMS

FIGURE 3



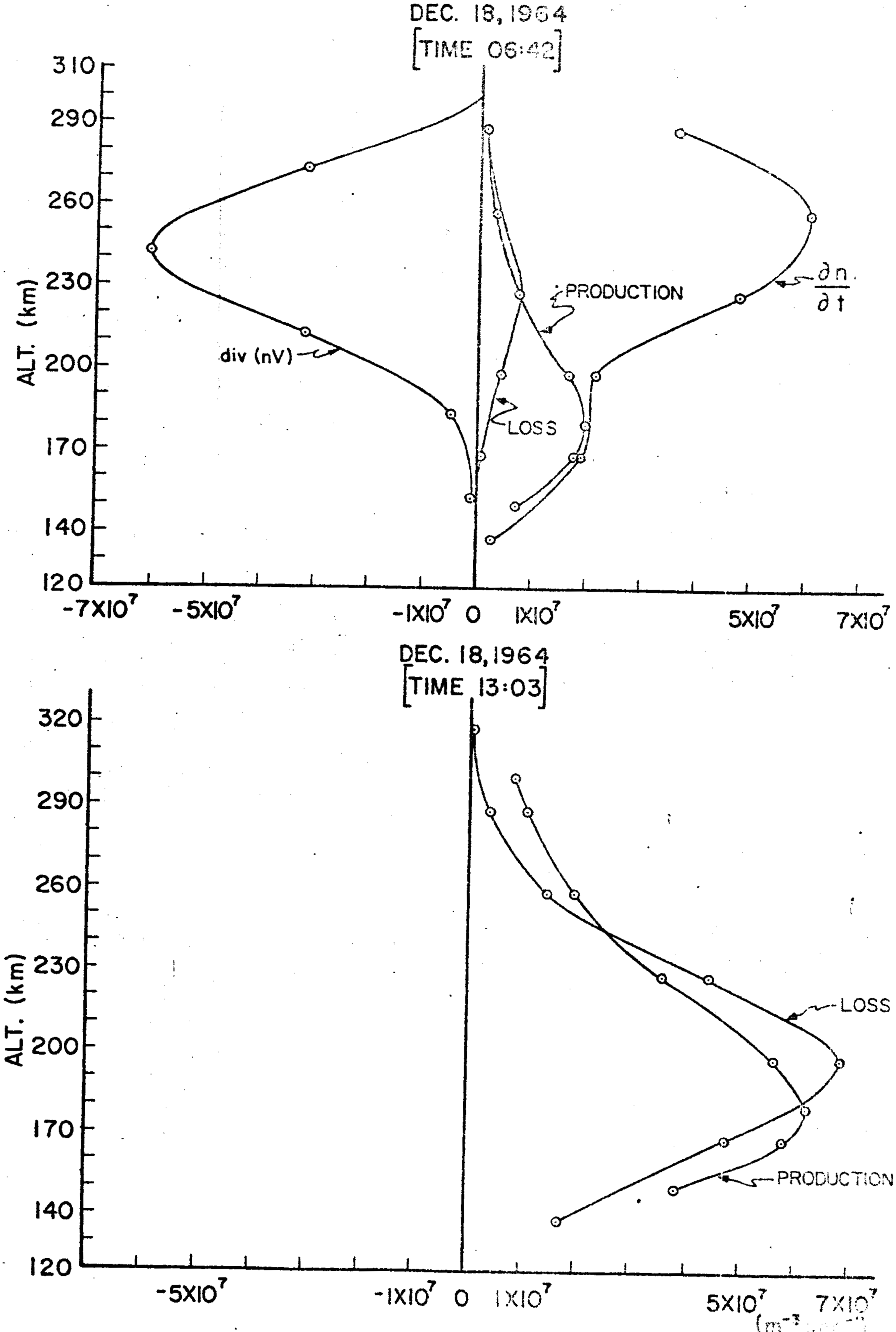
JULY 12, 13, 1964

FIGURE 4



ELECTRON CONTENT VS. TIME

FIGURE 5



CONTINUITY EQUATION TERMS

FIGURE 6

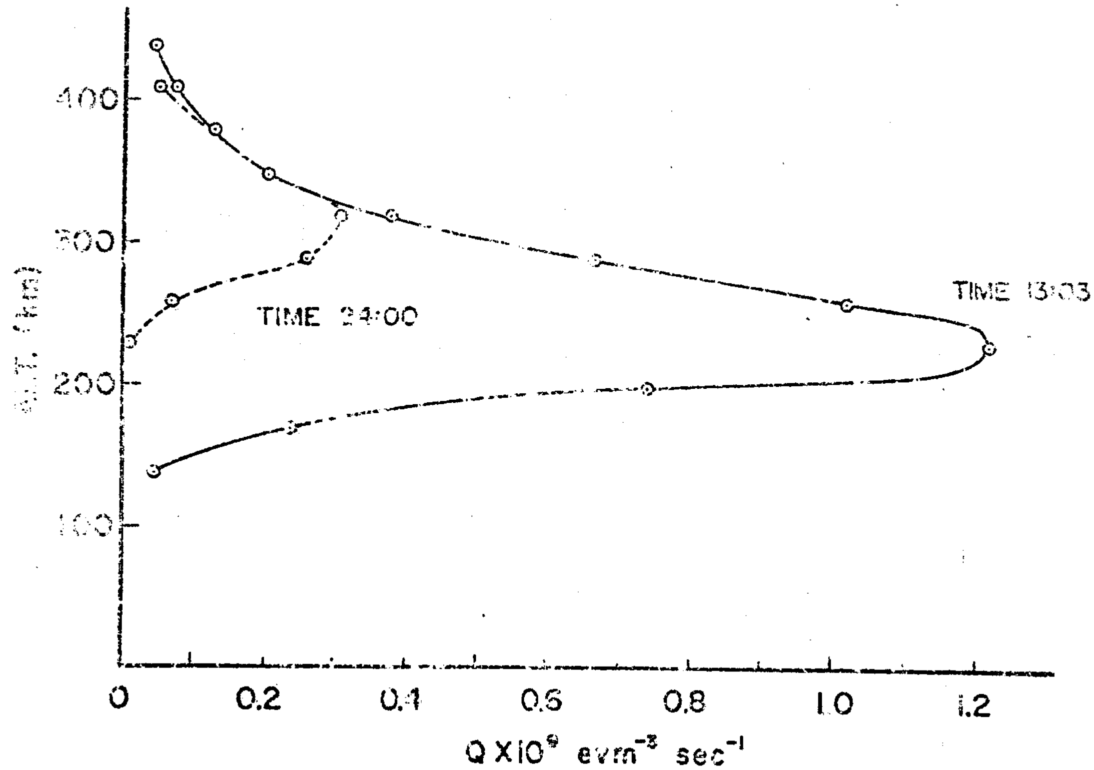


FIGURE 7A

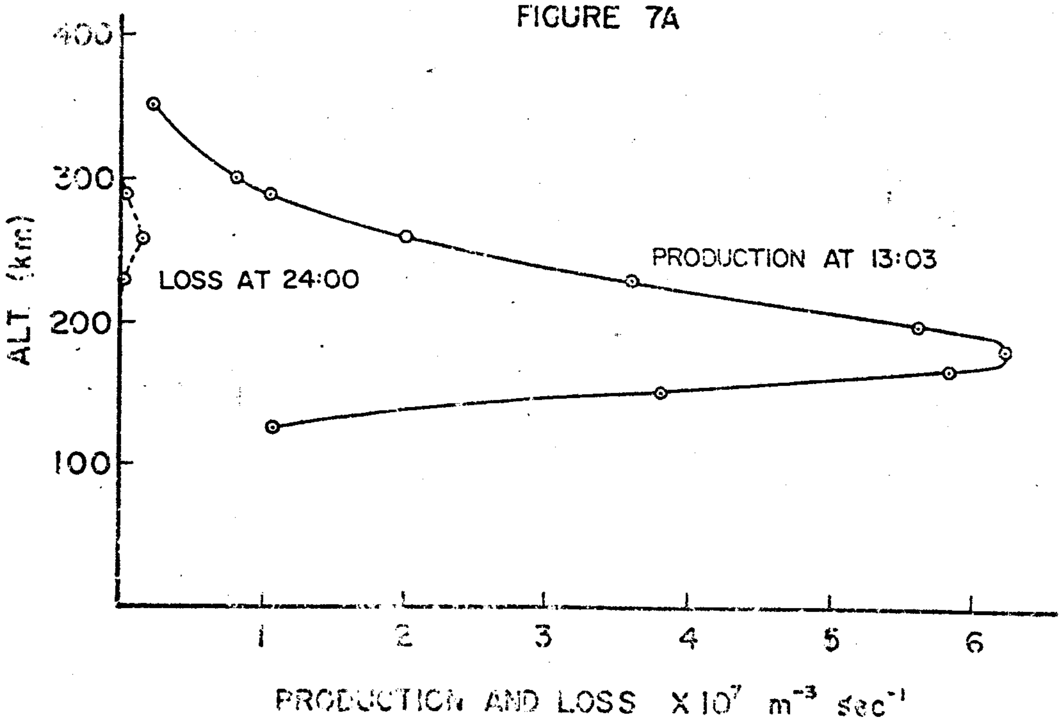


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FIGURE 7B